REPORT No. 295

THE VARIATION IN ENGINE POWER WITH ALTITUDE DETERMINED FROM MEASUREMENTS IN FLIGHT WITH A HUB DYNAMOMETER

By W. D. GOVE

Langley Memorial Aeronautical Laboratory

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SUMMARY

The rate of change in power of aircraft engines with altitude has been the subject of considerable discussion. Only a small amount of data from direct measurements of the power delivered by airplane engines during flight, however, has been published. This report presents the results of direct measurements of the power delivered by a Liberty 12 airplane engine taken with a hub dynamometer at standard altitudes from zero to 13,000 feet. Six flights were made with the engine installed in a modified DH-4 airplane. The tests were conducted at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics.

The experimental relation of brake horsepower to altitude is compared with two theoretical relations and with the experimental results, for a second Liberty 12 engine, given in N. A. C. A. Technical Report No. 252. The rate of change in power with altitude of a third Liberty engine, measured with a calibrated propeller, is also given for comparison.

The data presented substantiate the theoretical relation of brake horsepower to altitude based on the correction of ground level indicated horsepower for changes in atmospheric temperature and pressure with the subsequent deduction of friction horsepower corrected for altitude. The equation for this relation is

$$\mathrm{B.HP}_a = \mathrm{B.HP}_o\left[\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}\left(1+\frac{\lambda-\lambda n}{n}\right)-\left(\frac{\lambda-\lambda n}{n}\right)\right]$$

where P is the absolute atmospheric pressure, T is the absolute temperature, n is the mechanical efficiency of the engine at sea level and λ is the ratio of mechanical friction to friction horsepower at sea level. The subscripts $_o$ and $_a$ denote sea level and altitude conditions respectively.

INTRODUCTION

The effects of altitude conditions on the power delivered by airplane engines have been the subject of considerable discussion. However, there has been in the past very little information available for analysis and publication from the direct power measurements on airplane engines during flight. Further information has been obtained on the decrease in power delivered by a Liberty 12 engine with altitude during several flight tests made for the purpose of calibrating propellers. These tests were conducted at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, the engine power having been measured directly by means of a Bendemann type hub dynamometer. (Reference 1.) Six full throttle flights were made to approximately 13,000 feet altitude on which the engine speed was maintained practically constant by varying the altitude of the airplane. The relation of power to altitude, determined experimentally from these six flights, is compared with two theoretical relations in which sea level indicated horsepower is corrected for changes in atmospheric temperature and pressure at altitude. Further experimental evidence of the rate of change in power of a Liberty engine with altitude, taken from the data given in N. A. C. A. Technical Report No. 252 (reference 1), and from power measurements on a third Liberty engine made with a calibrated propeller, is also given for comparison.

METHODS AND APPARATUS

The flight tests were made as full throttle climbs to approximately 13,000 feet altitude on which measurements were taken of engine torque, engine speed, air speed, atmospheric pressure, atmospheric temperature, and carburetor air temperature. Engine speed was maintained as nearly constant as possible during these tests to avoid large speed corrections to power at altitudes where torque-engine speed relations were not known. For the small speed variations encountered, the engine power was corrected to a constant speed by ratio of the constant to the observed engine speeds.

Before an experimental relation of brake horsepower to altitude could be derived, it was necessary to correct the brake horsepower from existing flight conditions to the temperatures and pressures of the standard altitude at which the engine was considered to be operating. This standard altitude was taken as that corresponding to the density determined from the observed atmospheric pressure and temperature. (Reference 2.) A given air density may be obtained with a high temperature and pressure or with a low temperature and pressure while the power delivered by an engine under the two conditions would not be the same, density being a function of $\frac{P}{T}$, while indicated horsepower is a function of $\frac{P}{\sqrt{T}}$ (P denoting absolute pressure and T denoting absolute temperature). The observed power measurements were corrected for the differences between observed and standard altitude atmospheric conditions, by the direct ratio of standard altitude pressure to observed atmospheric pressure. A similar correction for temperature was also applied, using the inverse square-root relation. These corrections were applied directly to brake horsepower, rather than to indicated horsepower, for the reason that the pressure and temperature differences were small.

These flight tests were conducted with a modified DH–4 airplane powered with a Liberty 12 engine equipped with Zenith carburetors. Measurements of engine torque were obtained with a Bendemann type hub dynamometer which consists of a system of hydraulic pistons and cylinders interposed between the engine shaft and the propeller in such a manner that the hydraulic pressure generated in the cylinders is proportional to the torque. This pressure is transmitted through small tubes and recorded by an instrument in the cockpit. A more complete description of the Bendemann hub dynamometer is given in reference 1. All other measurements were recorded by means of an "automatic observer," developed by this committee, consisting essentially of a motor-driven motion-picture camera focused on the dials of indicating instruments mounted on a panel. These instruments consisted of an altimeter for the measurement of atmospheric pressure, an electric resistance thermometer for the measurement of atmospheric temperature, a distance type vapor pressure thermometer for the measurement of carburetor air temperature, an air-speed meter, and a chronometric tachometer.

RESULTS

Data from a representative climb are shown graphically in Figure 1 where brake horsepower, atmospheric pressure, atmospheric and carburetor air temperatures, engine speed and air speed are plotted against standard altitude. The data for the six flights analyzed in this report are given in Tables I to VI. Carburetor air temperatures are not given in the tables for the first five flights, because the thermometer used for this measurement was found from later calibrations to be unreliable.

The experimental relations of brake horsepower to altitude for all three engines are shown in Figure 2. The ratios of corrected brake horsepower at altitude to brake horsepower at zero altitude for each engine are plotted against standard altitude. Curve A of this figure represents the data taken from the engine used on the six flights at constant engine speed, curve B represents the relation for the engine used in the tests given in the report on the Bendemann hub dynamometer (reference 1), and curve C represents the power relation for the third engine where power was measured with a calibrated propeller.

Two theoretical relations of power to altitude, explained later in the report, are shown in Figure 3 as curves D and E. The experimental curve A of Figure 2 is also reproduced without

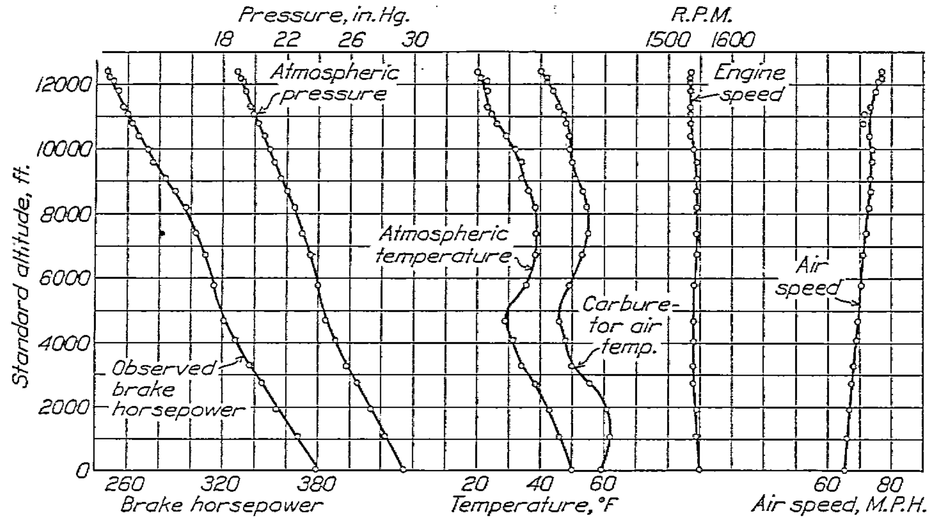

FIG. 1.—Data from a representative climb. Flight No. 6 of the modified DH-4 airplane with a Liberty 12 engine and a standard Martin bomber propeller

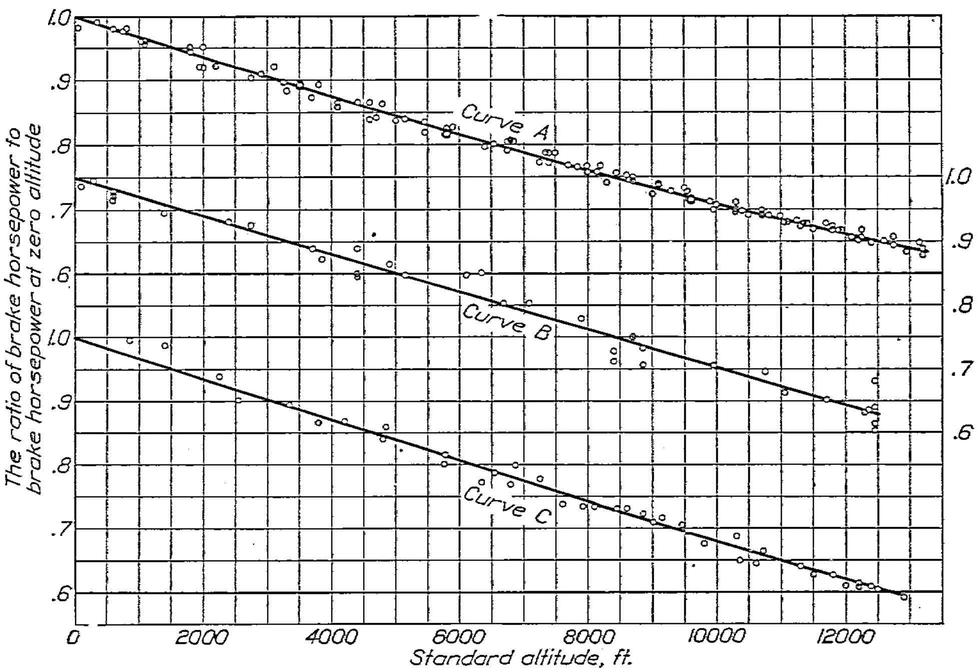

FIG. 2.—The percentage relation of brake horsepower to altitude for three Liberty 12 engines

data points to give a comparison of the two theoretical relations with the most reliable experimental relation.

Figure 4 illustrates the variation in the power delivered by the three engines with altitude. The more accurate theoretical relation of power to altitude, curve E, is also reproduced on this chart to show its agreement with all of the experimental data.

DISCUSSION OF RESULTS

Two theoretical relations of engine power to altitude are given for comparison with the relations determined experimentally from the three engines. The agreement of these theoretical relations with the experimental relations as represented by curves is taken as a criterion of the accuracy with which engine power at altitude can be computed from sea level engine performance.

The first relation is based on the assumption that indicated horsepower varies directly with pressure and inversely with the square root of the absolute temperature (reference 3),

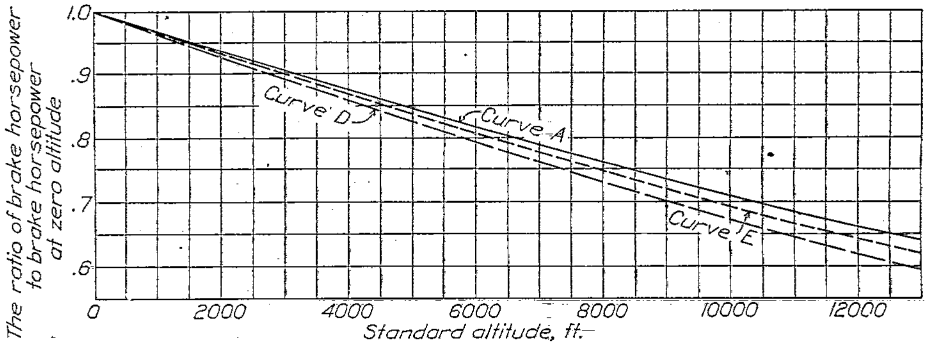

FIG. 3.—Comparison of the experimental percentage relation of power to altitude, determined from the six flights analyzed in this report, with two theoretical relations

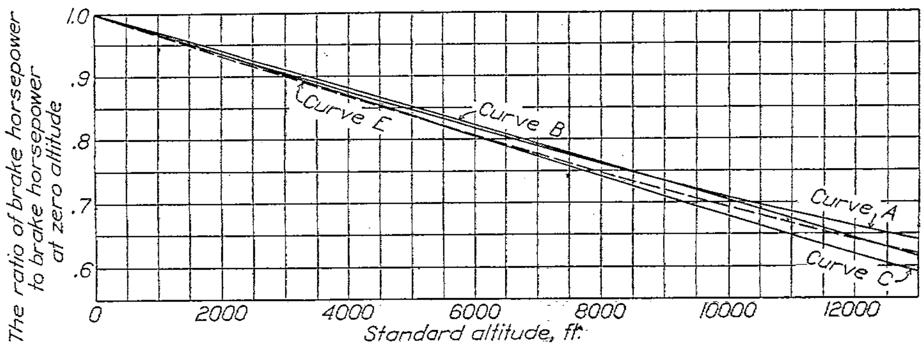

FIG. 4.—Comparison of the theoretical percentage relation of brake horsepower to altitude with curves determined experimentally from three Liberty 12 engines

and that the friction horsepower at constant engine speed is the same at all altitudes. This relation, based on brake horsepower at sea level and mechanical efficiency n, can be expressed as

$$\mathrm{B.HP_a}=\mathrm{B.HP_o}\left[\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}\left(\frac{1}{n}\right)-\frac{(1-n)}{n}\right]. \tag{1}$$

Curve D of Figure 3 is based on the above equation, using values of pressure and temperature from the standard altitude chart and a value of 88 per cent for mechanical efficiency at sea level. (Reference 4.) This relation gives 7 per cent less power at 12,000 feet altitude than that determined experimentally from the six flights.

The second method corrects indicated horsepower for temperature and pressure in the usual manner, and the friction horsepower for decreased pumping losses at altitude. The pumping losses were considered to vary directly with atmospheric pressure (reference 5) and inversely with the square root of the absolute temperature. Experimental justification of the latter assumption is found in the curves of friction horsepower versus temperature given in reference 6. The friction horsepower given in this report was divided into pumping losses and mechanical friction according to the ratio of pumping losses to friction horsepower given by Gage. (Reference 7.) From these data it was determined that the pumping losses varied with the square root of the absolute temperature ratio.

The second method, expressed in the form of an equation in terms of brake horsepower at sea level, mechanical efficiency at sea level, and the ratio of mechanical friction to sea level friction horsepower λ, becomes:

$$\mathrm{B.HP_a}=\mathrm{B.HP_o}\left[\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}\left(1+\frac{\lambda-\lambda n}{n}\right)-\left(\frac{\lambda-\lambda n}{n}\right)\right]. \tag{2}$$

Curve E of Figure 3 shows this relation as computed for the Liberty engine using a value of

λ equal to 0.5, as given in reference 7. This equation gives a closer estimation of power at altitude than equation (1), the discrepancy at 12,000 feet being only 3.5 per cent. A derivation of these two equations is given in the appendix.

The curves for the two theoretical relations have the same general form as the experimental relation determined from the six flights, although in both cases there is a gradual divergence with altitude. No attempt has been made to evolve a method of computing power at altitudes which would give closer agreement with this experimental relation than equation (2), because the power of different engines of the same model operating at the same altitude may vary as much as the percentage variation shown for the three engines in Figure 4. It may be seen that the theoretical curve given in this figure is in fair agreement with the experimental data from all three engines for the range of altitudes shown.

Of the three experimental relations given in Figures 2 and 4, curve A was the most accurately determined, both in the number of observations and in the refinement of methods with which they were taken. The variation of the test points from the average power curve for the data taken on these six flights was within plus or minus 2 per cent.

A comparison of the power developed at zero altitude for the engine, represented by curve A, with a calibration of the same engine, made in the laboratory with an electric dynamometer shows that less power was recorded with the engine installed in the airplane. The cause of this was not determined. However, since the laboratory calibration was made first, the decrease in power could be attributed to changes in condition of the engine with length of service. Were the power at zero altitude taken from the laboratory calibration, the ratios of power at altitude to power at zero altitude given in curve A, Figures 2 and 4 would be slightly lower, and the curve would agree more closely with the theoretical curve computed from equation (2).

Carburetor air temperatures measured in the inlet to the carburetor, on the flight for which the data is shown in Table VI, were found to be from 10° to 20° F. higher than the atmospheric temperatures. However, only a small error is incurred in using atmospheric rather than carburetor air temperatures in computing power at altitude from sea level engine power, for the reason that the temperature drop with altitude is very nearly the same for the atmospheric as for the carburetor air temperature as shown in Figure 1. All temperature corrections applied to both the theoretical and experimental power of engines in this report were based on the temperature of the air surrounding the engine rather than on the temperatures measured in the carburetor air-inlet passage.

CONCLUSIONS

The experimental results from the three Liberty 12 engines tested substantiate the second theoretical relation given in this report, the departure of any one of the experimental relations from the theoretical curve being less than plus or minus 3.5 per cent at 12,000 feet altitude. This theoretical relation is based on the correction of sea level indicated horsepower for changes in atmospheric temperature and pressure with the subsequent deduction of friction horsepower corrected for altitude and is expressed in the following equation:

$$\mathrm{B.HP}_a = \mathrm{B.HP}_o \left[\left(\frac{P_a}{P_o} \right) \left(\frac{T_o}{T_a} \right)^{1/2} \left(1 + \frac{\lambda - \lambda n}{n} \right) - \left(\frac{\lambda - \lambda n}{n} \right) \right]$$

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *May 7, 1928.*

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APPENDIX

Derivation of equation (1) (neglecting the decrease in pumping losses with altitude).
Assumptions:

(I) $$B.HP_a = I.HP_o \left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2} - F.HP_o$$

Let n = mechanical efficiency at sea level. Then

(II) $$I.HP_o = \frac{B.HP_o}{n} \text{ and } F.HP_o = \frac{(1-n)\ B.HP_o}{n},$$

Substituting (II) in (I)

(III) $$B.HP_a = \frac{B.HP_o}{n}\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2} - \frac{(1-n)\ B.HP_o}{n},$$

or,

Equation (1). $$B.HP_a = B.HP_o\left[\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}\left(\frac{1}{n}\right) - \left(\frac{1-n}{n}\right)\right].$$

Derivation of equation (2) (taking account of the decrease in pumping losses with altitude).
Assumptions:

(I) $$B.HP_a = I.HP_o \left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2} - F.HP_a$$

where $F.HP_a$ = mechanical friction at sea level plus pumping losses at sea level corrected to the temperature and pressure at altitude.

Let λ the ratio of mechanical friction to friction horsepower at sea level and n = mechanical efficiency at sea level.

Then

(II) $$I.HP_o = \frac{B.HP_o}{n},$$

and

(III) $$F.HP_a = \lambda\ F.HP_o + (1-\lambda)\ F.HP_o \left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}$$

but

(IV) $$F.HP_o = \frac{(1-n)\ B.HP_o}{n},$$

hence

(V) $$F.HP_a = \frac{\lambda\ (1-n)\ B.HP_o}{n} + \frac{(1-\lambda)\ (1-n)\ B.HP_o}{n}\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}$$

Substituting values from (II) and (V) in (I).

(VI) $$B.HP_a = \frac{B.HP_o}{n}\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2} - \frac{\lambda\ (1-n)\ B.HP_o}{n} - \frac{(1-\lambda)\ (1-n)\ B.HP_o}{n}\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2},$$

simplifying

Equation (2). $$B.HP_a = B.HP_o\left[\left(\frac{P_a}{P_o}\right)\left(\frac{T_o}{T_a}\right)^{1/2}\left(1 + \frac{\lambda - \lambda n}{n}\right) - \left(\frac{\lambda - \lambda n}{n}\right)\right].$$

TABLE 1

Reading No.	Atmospheric pressure (inches Hg.)	Atmospheric temperature (°F. Abs.)	Standard altitude (feet)	R. P. M.	Airspeed (M. P. H.)	Observed B. HP.	Standard altitude pressure (inches Hg.)	Pressure correction factor	Standard altitude temperature (°F. Abs.)	Temperature correction factor	B. HP. corrected for T. and P. at observed R. P. M.	Corrected B. HP. at 1,400 R. P. M.	Ratio corrected B. HP. to B. HP_o= 356
1	27. 50	482	350	1, 400	73. 0	341	29. 55	1. 074	517	0. 965	353	353	0. 992
2	26. 65	478	1, 100	1, 400	74. 0	329	28. 75	1. 078	514	. 964	352	342	. 961
3	25. 80	475	2, 000	1, 405	75. 0	317	27. 82	1. 078	511	. 964	329	328	. 921
4	24. 85	481	3, 700	1, 410	77. 0	305	26. 13	1. 052	505	. 975	313	311	. 874
5	24. 15	481	4, 600	1, 405	77. 5	293	25. 27	1. 047	502	. 978	300	299	. 840
6	23. 55	481	5, 450	1, 405	78. 0	287	24. 47	1. 038	499	. 981	293	292	. 820
7	22. 85	480	6, 400	1, 405	78. 5	280	23. 62	1. 034	496	. 984	285	284	. 798
8	22. 20	480	7, 250	1, 405	79. 0	272	22. 86	1. 029	493	. 985	276	275	. 773
9	21. 80	480	7, 850	1, 405	79. 0	270	22. 35	1. 026	490	. 989	274	273	. 767
10	21. 35	478	8, 450	1, 405	79. 5	268	21. 84	1. 023	488	. 989	271	270	. 758
11	20. 90	478	9, 100	1, 400	79. 5	260	21. 30	1. 018	486	. 992	263	263	. 739
12	20. 55	476	9, 550	1, 400	79. 5	256	20. 94	1. 018	484	. 992	259	259	. 728
13	20. 25	475	9, 950	1, 400	79. 5	247	20. 62	1. 018	483	. 992	249	249	. 700
14	19. 90	475	10, 500	1, 400	80. 0	244	20. 18	1. 013	481	. 994	246	246	. 691
15	19. 55	475	11, 050	1, 400	80. 0	240	19. 75	1. 011	479	. 996	242	242	. 680
16	19. 30	475	11, 500	1, 400	80. 0	237	19. 41	1. 006	477	. 998	238	238	. 669

Data from flight No. 1 of a modified DH-4 airplane with a Liberty 12 engine and a Martin bomber supercharger propeller.

TABLE 2

Reading No.	Atmospheric pressure (inches Hg.)	Atmospheric temperature (°F. Abs.)	Standard altitude (feet)	R. P. M.	Airspeed (M. P. H.)	Observed B. HP.	Standard altitude pressure (inches Hg.)	Pressure	Standard ... Abs.)	Tempera-	B. HP. corrected for T. and P. at observed R. P. M.	Corrected B. HP. at 1,550 R. P. M.	Ratio corrected B. HP to B. HP_o= 384
1	28. 15	497	600	1, 540	75. 0	368	29. 28	1. 040	516	0. 980	375	377	0. 982
2	26. 95	493	1, 800	1, 550	76. 5	358	28. 02	1. 040	512	. 982	366	366	. 953
3	25. 95	500	3, 500	1, 555	78. 0	345	26. 32	1. 014	506	. 984	344	343	. 893
4	25. 05	500	4, 600	1, 570	79. 0	335	25. 27	1. 008	502	. 998	337	333	. 867
5	24. 30	497	5, 450	1, 550	79. 5	320	24. 47	1. 006	499	. 997	321	321	. 836
6	23. 35	497	6, 850	1, 550	80. 0	311	23. 21	. 995	494	1. 002	310	310	. 807
7	22. 85	495	7, 350	1, 550	80. 5	302	22. 78	. 997	492	1. 002	302	302	. 787
8	22. 30	492	8, 000	1, 550	81. 5	294	22. 22	. 997	490	1. 002	294	294	. 766
9	21. 70	489	8, 600	1, 545	82. 0	287	21. 72	1. 000	488	1. 000	287	288	. 753
10	21. 25	485	9, 000	1, 550	83. 0	277	21. 39	1. 007	486	. 999	278	278	. 724
11	20. 85	484	9, 600	1, 535	84. 0	272	20. 90	1. 002	484	1. 000	272	275	. 716
12	20. 50	484	10, 300	1, 540	84. 5	270	20. 34	. 992	482	1. 002	268	269	. 700
13	20. 00	481	10, 700	1, 545	85. 0	266	20. 03	. 998	480	1. 000	265	266	. 693
14	19. 60	481	11, 400	1, 545	85. 5	259	19. 48	. 994	478	1. 002	258	259	. 677
15	19. 25	481	11, 900	1, 545	86. 0	256	19. 11	. 993	476	1. 005	255	256	. 667
16	18. 95	484	12, 600	1, 545	87. 0	251	18. 58	. 981	473	1. 011	249	250	. 651
17	18. 60	484	13, 200	1, 545	88. 0	247	18. 14	. 975	471	1. 013	244	245	. 638

Data from flight No. 2 of a modified DH-4 airplane with a Liberty 12 engine and a standard Martin bomber propeller.

TABLE 3

Reading No.	Atmospheric pressure (inches Hg.)	Atmospheric temperature (°F. Abs.)	Standard altitude (feet)	R. P. M.	Airspeed (M. P. H.)	Observed B. HP.	Standard altitude pressure (inches Hg.)	Pressure correction factor	Standard altitude temperature (°F. Abs.)	Temperature correction factor	B. HP. corrected for T. and P. at observed R. P. M.	Corrected B. HP. at 1,550 R. P. M.	Ratio corrected B. HP. to B. HP.$_0$=384
1	28. 60	507	750	1, 555	75. 0	372	29. 22	1. 022	516	0. 991	377	376	0. 979
2	27. 55	504	1, 800	1, 555	76. 0	361	28. 02	1. 017	512	. 992	364	363	. 946
3	26. 55	501	2, 900	1, 550	76. 5	348	26. 91	1. 013	508	. 992	350	350	. 911
4	25. 80	496	3, 500	1, 550	77. 0	339	26. 32	1. 021	506	. 990	343	343	. 893
5	24. 95	493	4, 400	1, 550	77. 5	330	25. 46	1. 021	503	. 990	333	333	. 867
6	24. 25	490	5, 150	1, 550	78. 0	320	24. 75	1. 021	500	. 990	323	323	. 841
7	23. 65	487	5, 800	1, 550	78. 5	311	24. 16	1. 021	498	. 988	314	314	. 818
8	23. 00	485	6, 550	1, 550	79. 0	305	23. 48	1. 021	495	. 990	308	308	. 802
9	22. 40	489	7, 700	1, 550	80. 0	295	22. 48	1. 002	491	. 998	295	295	. 768
10	21. 85	492	8, 650	1, 550	81. 0	287	21. 76	. 996	488	1. 003	287	287	. 747
11	21. 40	492	9, 300	1, 545	82. 0	879	21. 14	. 988	485	1. 007	279	280	. 729
12	21. 60	492	9, 900	1, 545	82. 5	275	20. 66	. 984	483	1. 008	273	274	. 713
13	20. 75	490	10, 300	1, 545	83. 0	270	20. 34	. 980	482	1. 009	267	268	. 698
14	20. 40	489	10, 700	1, 545	83. 0	267	20. 03	. 983	480	1. 009	264	265	. 690
15	20. 10	487	11, 000	1, 545	83. 5	266	19. 79	. 984	479	1. 008	264	265	. 690
16	19. 75	484	11, 350	1, 545	84. 0	260	19. 56	. 990	478	1. 006	259	260	. 677
17	19. 40	482	11, 800	1, 545	84. 5	259	19. 18	. 990	475	1. 007	258	259	. 674
18	19. 05	481	12, 250	1, 545	85. 0	256	18. 84	. 988	474	1. 007	255	256	. 667
19	18. 75	481	12, 750	1, 545	85. 5	253	18. 46	. 985	473	1. 008	251	252	. 656
20	18. 50	481	13, 150	1, 545	86. 0	250	18. 17	. 982	471	1. 010	248	249	. 648

Data from flight No. 3 of a modified DH–4 airplane with a Liberty 12 engine and a standard Martin bomber propeller.

TABLE 4

Reading No.	Atmospheric pressure (inches Hg.)	Atmospheric temperature (°F. Abs.)	Standard altitude (feet)	R. P. M.	Airspeed (M. P. H.)	Observed B. HP.	Standard altitude pressure (inches Hg.)	Pressure correction factor	Standard altitude temperature (°F. Abs.)	Temperature correction factor	B. HP. corrected for T. and P. at observed R. P. M.	Corrected B. HP. at 1,550 R. P. M.	Ratio corrected B. HP. to B. HP.$_0$=384
1	28. 70	509	800	1, 560	75. 5	379	29. 07	1. 008	516	0. 993	379	377	0. 982
2	27. 60	508	2, 000	1, 560	76. 5	367	27. 82	1. 008	511	. 997	368	366	. 953
3	26. 50	503	3, 100	1, 560	77. 5	355	26. 72	1. 008	507	. 994	356	354	. 922
4	25. 70	500	3, 800	1, 555	78. 0	342	26. 03	1. 013	505	. 995	344	343	. 893
5	24. 75	497	4, 800	1, 555	79. 0	330	25. 08	1. 013	501	. 996	333	332	. 865
6	24. 00	497	5, 900	1, 555	80. 0	318	24. 07	1. 003	497	1. 000	319	318	. 828
7	23. 35	497	6, 800	1, 555	80. 5	311	23. 26	. 997	494	1. 002	311	310	. 807
8	22. 70	493	7, 500	1, 555	81. 0	303	22. 65	. 998	492	1. 000	303	302	. 787
9	22. 15	490	8, 150	1, 555	82. 0	293	22. 09	. 997	489	1. 000	292	291	. 758
10	21. 60	487	8, 700	1, 550	83. 0	286	21. 64	1. 002	487	1. 000	286	286	. 745
11	21. 10	489	9, 500	1, 550	84. 0	282	20. 98	. 995	485	1. 004	282	282	. 734
12	20. 70	489	10, 300	1, 550	84. 5	275	20. 34	. 984	482	1. 008	273	273	. 711
13	20. 30	487	10, 700	1, 550	85. 0	270	20. 03	. 987	480	1. 007	268	268	. 698
14	19. 90	486	11, 250	1, 550	85. 5	266	19. 60	. 995	478	1. 007	266	266	. 682
15	19. 55	484	11, 700	1, 550	86. 0	260	19. 26	. 995	477	1. 008	260	260	. 677
16	19. 30	482	11, 950	1, 545	86. 5	256	19. 07	. 988	476	1. 006	255	256	. 667
17	19. 05	481	12, 250	1, 545	87. 0	253	18. 84	. 989	475	1. 006	252	253	. 657
18	18. 75	481	12, 750	1, 545	88. 0	248	18. 47	. 985	473	1. 008	246	247	. 643
19	18. 60	481	12, 950	1, 545	89. 0	244	18. 32	. 984	472	1. 008	242	243	. 633
20	18. 40	480	13, 200	1, 545	90. 0	241	18. 14	. 986	471	1. 011	240	241	. 627

Data from flight No. 4 of a modified DH–4 airplane with a Liberty 12 engine and a standard Martin bomber propeller.

TABLE 5

Reading No.	Atmospheric pressure (inches Hg.)	Atmospheric temperature (°F. Abs.)	Standard altitude (feet)	R. P. M.	Airspeed (M. P. H.)	Observed B. HP.	Standard altitude pressure (inches Hg.)	Pressure	Standard Abs.)	Tempera-	B. HP. corrected for T and P. at observed R. P. M.	Corrected B. HP. at 1,550 R. P. M.	Ratio corrected B. HP. to B. HP_o= 384
1	27. 85	497	1, 050	1, 545	66. 0	363	28. 80	1. 033	515	0. 982	368	369	0. 961
2	26. 90	497	2, 200	1, 545	67. 5	350	27. 62	1. 027	511	. 986	354	355	. 924
3	26. 00	496	3, 250	1, 545	68. 0	340	26. 57	1. 022	507	. 990	344	345	. 898
4	25. 25	494	4, 100	1, 545	69. 0	329	25. 74	1. 018	504	. 991	332	333	. 867
5	24. 40	490	5, 000	1, 545	70. 0	319	24. 89	1. 019	501	. 989	321	322	. 839
6	23. 75	490	5, 800	1, 540	70. 0	309	24. 16	1. 017	498	. 992	312	314	. 818
7	23. 15	490	6, 750	1, 535	71. 0	301	23. 30	1. 007	494	. 995	301	304	. 792
8	22. 65	490	7, 400	1, 535	71. 5	294	22. 74	1. 004	492	. 998	294	297	. 773
9	22. 25	490	8, 000	1, 540	72. 0	289	22. 22	1. 000	490	1. 000	289	291	. 758
10	21. 90	487	8, 300	1, 545	72. 0	284	21. 97	1. 002	489	. 998	284	285	. 742

Data from flight No. 5 of a modified DH-4 airplane with a Liberty 12 engine and a standard Martin bomber propeller.

TABLE 6

Reading No.	Atmospheric pressure (inches Hg.)	Atmospheric temperature (°F Abs.)	Standard altitude (feet)	Carburetor air temperature (°F. Abs.)	R. P. M.	Airspeed (M. P. H.)	Observed B. HP.	Standard altitude pressure (inches Hg.)	Pressure correction factor	Standard altitude temperature (°F. Abs.)	Temperature correction factor	B. HP. corrected for T. and P. at observed R. P. M.	Corrected B.HP. at 1,550 R. P. M.	Ratio corrected B. HP. to B. HP_o=384
1	29. 40	509	50	518	1, 550	65. 5	379	29. 86	1. 016	518	0. 991	378	378	0. 984
2	28. 25	505	1, 100	521	1, 545	66. 0	368	28. 75	1. 017	515	. 991	367	368	. 958
3	27. 40	502	1, 950	520	1, 545	67. 0	354	27. 87	1. 017	511	. 991	353	354	. 922
4	26. 50	498	2, 750	515	1, 540	67. 5	345	27. 06	1. 021	509	. 990	345	347	. 904
5	25. 80	493	3, 300	509	1, 540	68. 0	337	26. 52	1. 028	507	. 987	338	340	. 885
6	25. 10	491	4, 100	507	1, 540	69. 0	328	25. 74	1. 025	504	. 987	328	330	. 860
7	24. 50	488	4, 700	505	1, 540	69. 5	321	25. 17	1. 027	502	. 986	322	324	. 844
8	24. 00	495	5, 800	508	1, 540	70. 5	315	24. 16	1. 007	498	. 996	316	317	. 826
9	23. 50	498	6, 750	512	1, 545	71. 0	309	23. 31	. 992	494	1. 004	308	309	. 805
10	23. 00	498	7, 400	514	1, 545	72. 0	303	22. 74	. 988	492	1. 007	301	302	. 786
11	22. 50	498	8, 200	514	1, 545	73. 0	297	22. 05	. 980	489	1. 010	294	295	. 768
12	22. 05	496	8, 700	513	1, 545	73. 5	290	21. 64	. 981	487	1. 008	287	288	. 750
13	21. 65	493	9, 100	510	1, 545	73. 5	284	21. 30	. 984	486	1. 008	282	283	. 737
14	21. 25	493	9, 600	509	1, 545	74. 0	276	20. 90	. 983	484	1. 011	274	275	. 716
15	20. 95	491	10, 000	508	1, 540	74. 0	273	20. 58	. 982	483	1. 008	270	272	. 708
16	20. 60	488	10, 400	508	1, 535	73. 0	267	20. 26	. 984	481	1. 008	265	268	. 698
17	20. 20	485	10, 800	507	1, 535	71. 0	263	19. 95	. 988	480	1. 006	262	265	. 690
18	19. 90	484	11, 100	507	1, 535	71. 5	260	19. 72	. 991	479	1. 006	259	262	. 682
19	19. 70	482	11, 300	505	1, 535	73. 5	257	19. 56	. 994	479	1. 002	256	259	. 674
20	19. 40	482	11, 800	503	1, 535	75. 0	254	19. 18	. 988	476	1. 006	253	256	. 667
21	19. 25	482	12, 100	501	1, 535	76. 0	251	18. 96	. 985	475	1. 007	249	252	. 656
22	19. 10	480	12, 200	501	1, 535	77. 0	248	18. 88	. 988	475	1. 007	247	250	. 651
23	18. 90	479	12, 400	499	1, 535	77. 0	247	18. 73	. 991	474	1. 006	246	249	. 648

Data from flight No. 6 of a modified DH-4 airplane with a Liberty 12 engine and a standard Martin bomber propeller.